CS514: Intermediate Course in Computer Systems

Lecture 15: February 24, 2003

Overcoming network outages in applications that need high availability

Network outages

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- We've seen a number of security mechanisms
  - VPNs
  - Firewalls and address translators
- And these run over the Internet itself
  - But problems can arise in the network
  - To what degree can an application "secure itself" against such outages?

Handling network failures

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- Networks are themselves fault-tolerant
  - Assuming there is an alternative route!
  - Routing protocols detect problems and adapt when a destination becomes unreachable by its previously best route
  - But route changes don't happen instantly. Delays of many seconds or even minutes are common
- Moreover, network routing deals only with certain classes of failure
  - For example, *overload* is not treated as a good reason for quickly changing routing

A bit of history

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- Prior to 1980, Internet routing was extremely responsive
  - But around 1980, studies showed that as much as 1/3 of the bandwidth of the Internet was consumed purely by routing protocols!
  - Moreover, the growth was worse than linear
- In early 1980's the concept of adaptive routine was revisited to address these problems

Streams concept revisited

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- TCP supports "streams": reliable, point-to-point communication (also called a "flow")
- Like a telephone connection:
  - Information received in order sent, no loss or duplication
  - Call setup required before communication is possible (in contrast with basic message transport via UDP)
  - No message structure: abstraction is a stream of bytes
- Automatic flow control, error correction

TCP sliding window

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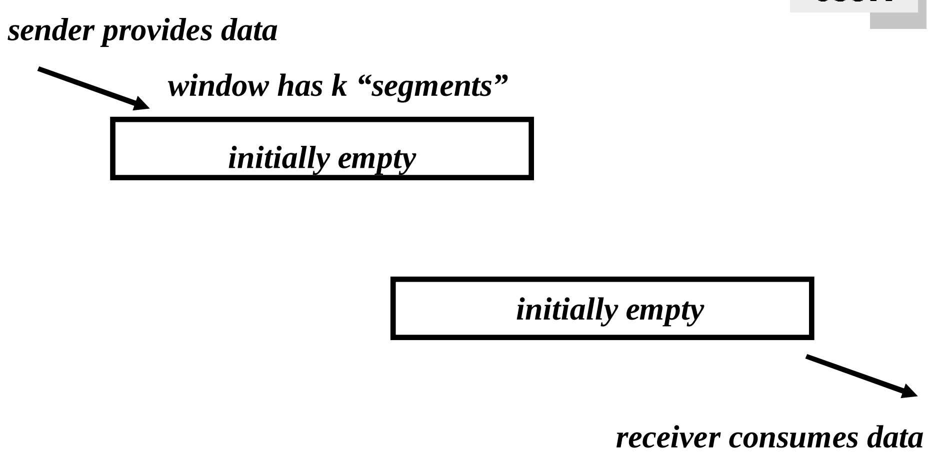

TCP sliding window

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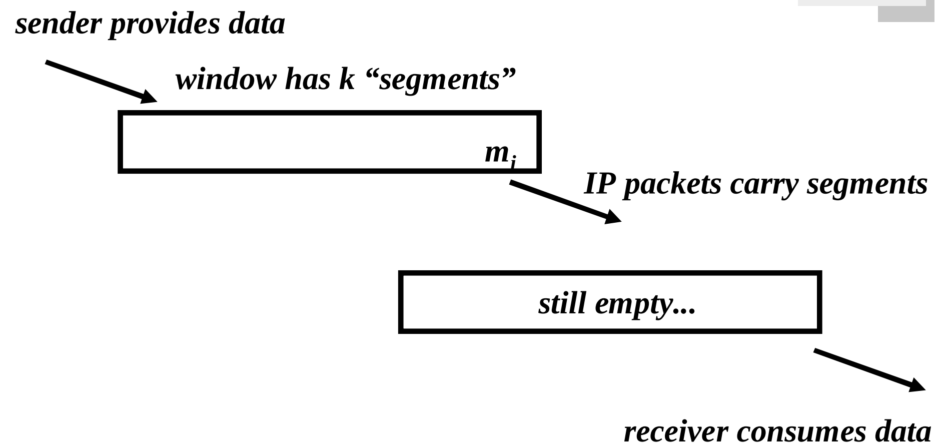

TCP sliding window

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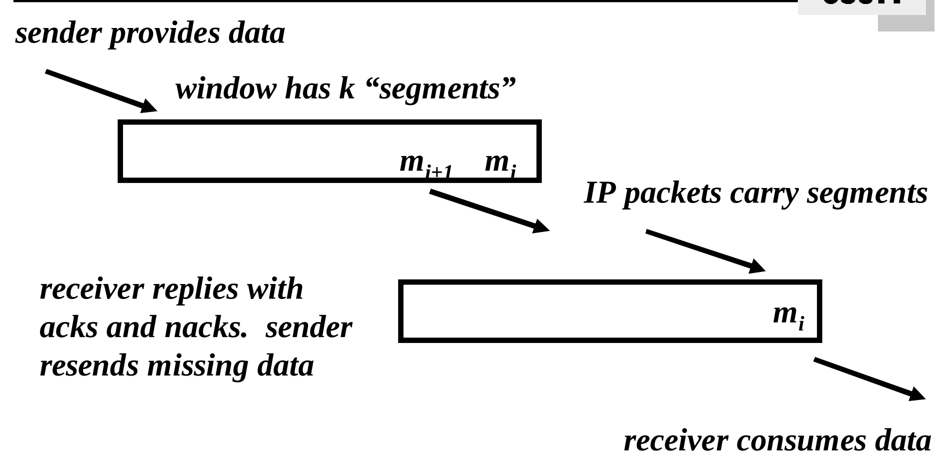

TCP sliding window

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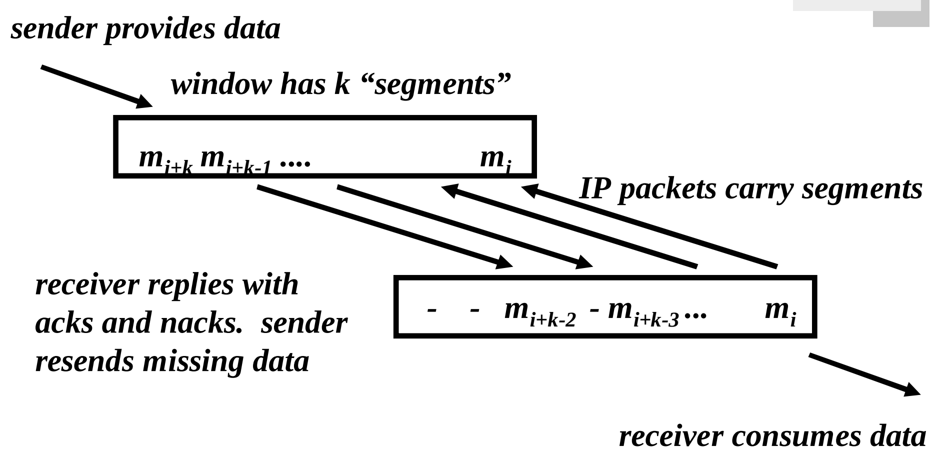

TCP sliding window

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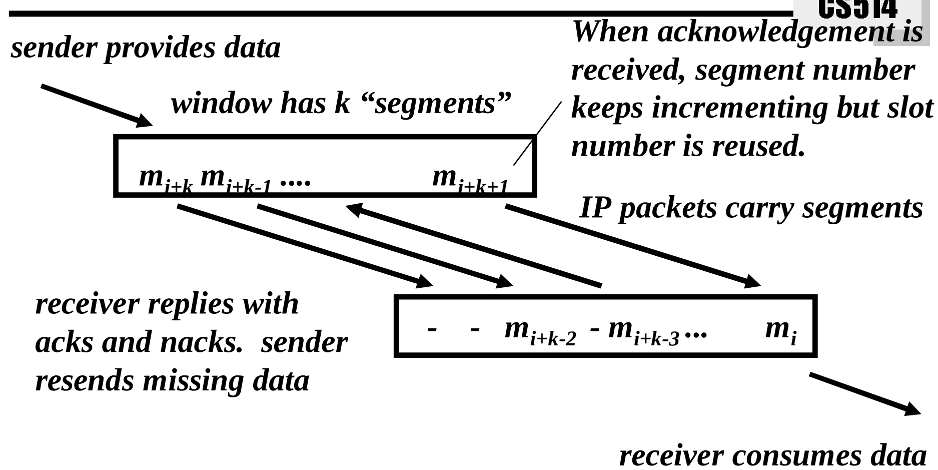

TCP sliding window

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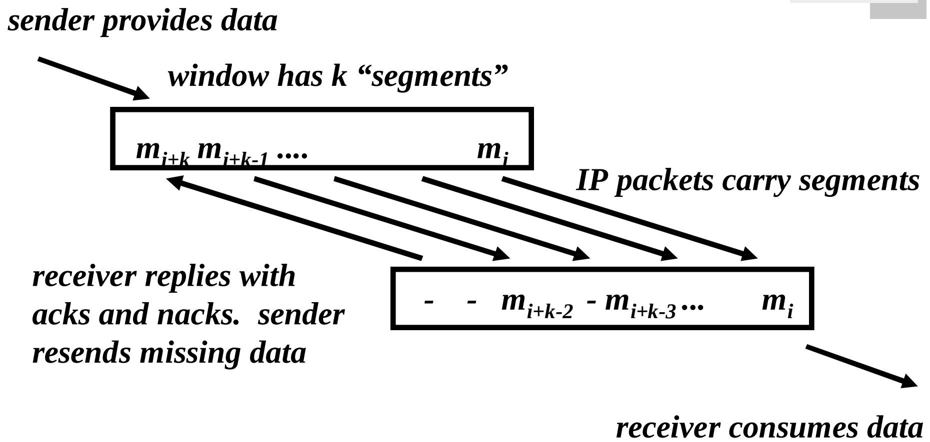

Why use a window?

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- TCP wants to match
  - Rate that the sender is transmitting
  - Speed that the network can handle
  - Rate that the receiver can handle
- It wants to hide the end-to-end latency associated with the network
  - Applications want to do as few context switching or blocking events as possible
- So TCP acts like a bounded buffer with high and low-water marks, as used in the O/S

Typical implementation issues?

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- When to send the ack
  - Send early: inefficient, channel clogged with acks
  - Send late: sender side fills window and waits
- When to send the nack
  - Send early: sender will send duplicates of all msgs
  - Send late: long delay waiting for desired data
- How big to make the window
- Send messages in “bursts”?

Where are the costs?

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- Excess packets sent/received: very costly
  - Hence want minimal number of acks, nacks
  - Also want to avoid excess retransmissions
- Notice “tension” between sending acks/nacks too soon, and retransmission too soon, and between doing so too late.
  - Too soon: consumes bandwidth
  - Too late: leaves processes idle

Costs (cont)

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- Delays on sender side:
  - Overheads associated with scheduling (e.g. if window fills up
- Avoiding “nervous” scheduling:
  - High-water/low-water mark scheme lets sender sit idle until there are several window slots free
  - Ideally, seek window size at which sender, receiver are rate matched and neither ever waits

Costs (cont)

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- Delays on receiver side
  - Want a large enough window so that any error correction is “in the future” for receiver
  - Don’t want to delay nacks too long (else retransmission delayed too long)
- Nervous scheduling less of an issue here
  - Don’t use hi-water/low-water scheme in receiver

Timed approach

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- Measure round-trip time (e.g. perhaps 1ms)
- Track rate of transmission for recent past
- Use to calibrate various constants:
  - Nack if a missing packet is late by 50% of expected time
  - Calibrate window to be 50-75% full in steady state
- Experience: very hard to make it work; variability in network load/latencies too big

Van Jacobson optimizations

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- Dynamically adjust window size
  - While no loss detected, repeatedly increase size (linearly)
  - Detect loss: halve size ("multiplicative" backoff)
- Experience is very positive, many TCP's use this

Dealing with failures

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- Packets lost, duplicated, out of order: easy, just use sequence numbers (TCP calls these "segment" numbers)
- Sender or receiver fails, or line breaks:
  - After excessive retransmissions, or
  - After excessive wait for missing data, or
  - After not seeing "keepalives" for too long

  … ***break the connection and report "end of file"***

TCP rate at sender

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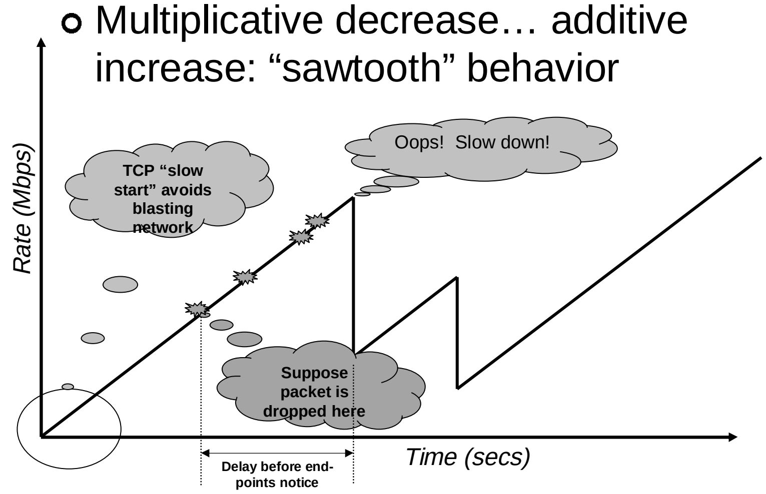
- Multiplicative decrease… additive increase: "sawtooth" behavior



Issue of “catastrophic collapse”

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- Suppose that many TCP flows run through the same router
  - They need time to notice packet loss and slow down
  - So they could overwhelm the router for many seconds before packet loss forces them to back off
- During this period the router basically dies
  - Worse still, a few aggressive flows could kill the router for all flows using it!

Sudden collapse

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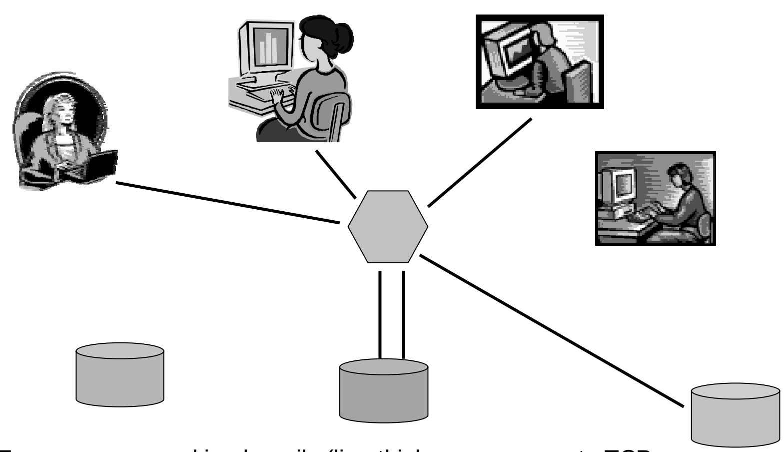

Everyone was working happily (line thickness represents TCP bandwidth)…. When suddenly….

Sudden collapse

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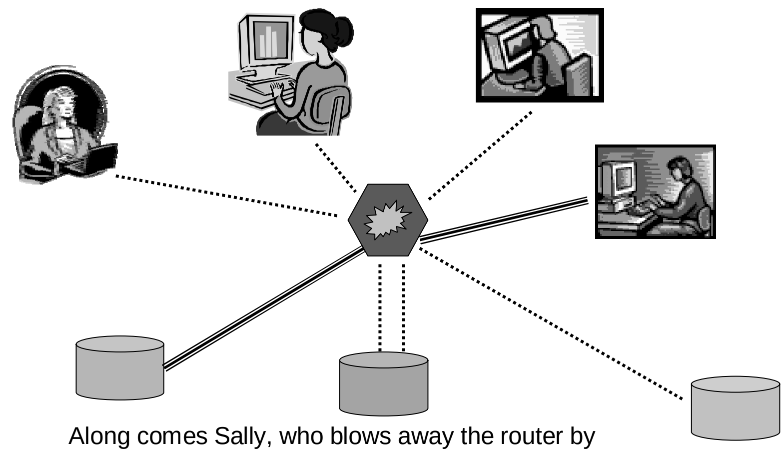

Along comes Sally, who blows away the router by transferring a huge object at very high rates!

TCP slow start

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- Try to avoid blasting router by having a TCP connection
  - Start sending slowly, not rapidly
  - Do this if it has been idle for more than a few seconds
- Idea is that we sort of “feel out the lay of the land” before overwhelming the network by accident

Random Early Detection (RED)

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- Idea is to have the router anticipate that it is approaching a congestion state
  - Router notices this *well before* the problem actually arises
  - It signals the problem by randomly dropping some packets
- The faster a TCP flow is running the more likely it will lose some packets!
- So RED encourages fast TCP protocols to slow down before they mess up the router for everyone!

What does this add up to?

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- End-user must expect
  - Variable TCP bandwidths
  - Potential loss of a TCP connection if an extended network outage occurs
  - Slow start after a period of idleness
- This behavior is as visible in a LAN shared with other users as it is in the Internet WAN

Back to routing…

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- Recall that the Internet routes around faults
  - Clearly, if it routes around congestion, that will defeat the delicate dance between RED and TCP!
  - Moreover, back in 1980, *most* routing changes were triggered by load
- So the modern Internet is deliberately slow to reroute. Minutes, not seconds

Pulling it all together…

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- So suppose you need to build a highly available application on a network
  - That network probably runs TCP on normal routers
  - So it will probably behave like the Internet if it gets heavily loaded!
  - Outages lasting minutes could be common…

Other problems with TCP as a transport?

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- A TCP channel can break because of a transient condition!
  - Example: overloaded machine, connection that temporarily fails, router crashes and must reboot itself (all are relatively common conditions)
- Systems with many TCP channels: *some may break but others stay connected!*
  - Famous example: FTP uses two connections between client and server. In fact one could break while other remains open!

Inconsistently broken TCP channels

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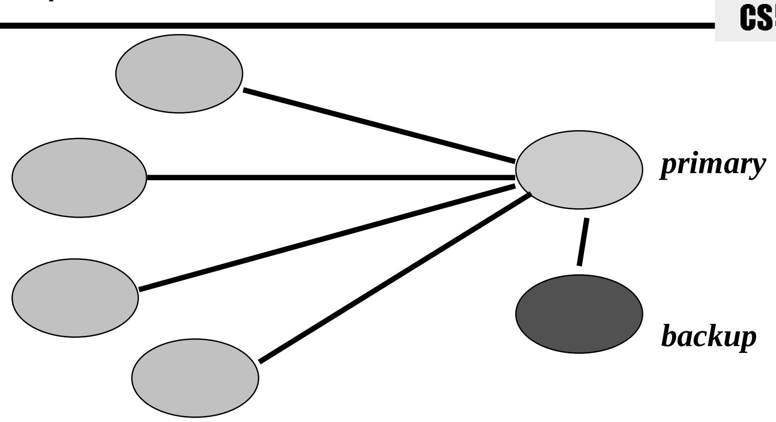

Clients initially connected to primary, which keeps backup up to date. (For example, in a database system)

Inconsistently broken TCP channels

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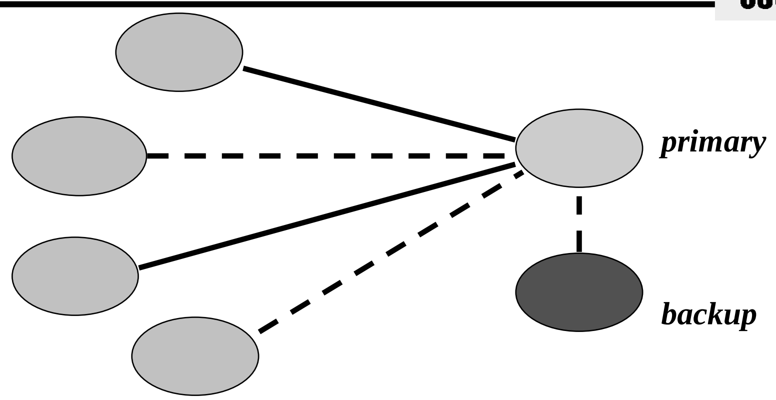

Transient problem causes some links to break but not all. Backup thinks it is now primary, primary thinks backup is down

Inconsistently broken TCP channels

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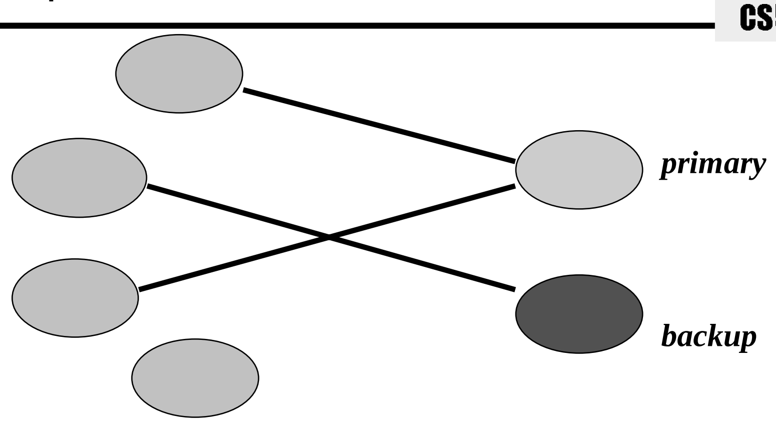

Some clients still connected to primary, but one has switched to backup and one is completely disconnected from both

Why should this matter?

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- Suppose that primary and backup are a service used for air traffic control
- Service tells controllers which parts of airspace are “available” for routing flights towards airport
- Primary and backup may try and give *different* controllers access to the *same* airspace! Each thinks it is “in charge” for the system as a whole!

Subtle semantics questions

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- Are the “reliability semantics” of TCP actually different from those of RPC?
  - In both cases, what you “know” is limited to what has been explicitly acknowledged
  - Both can report “failures” when none has occured
  - Ultimately, TCP and RPC give same guarantees!
- Many systems run RPC over TCP as the “reliable” RPC option. Is this different from normal RPC?

Reliability/Consistency summary

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- TCP connections can overcome loss of individual packets in communication layer
  - Remote method invocation protocols running on UDP also overcome such loss
  - Both forms of connections report failures inconsistently
- Not clear how either could be used to implement a “safe” primary-backup server for our ATC example!
- And application must struggle with unpredictable bandwidth…

Typical application-level issues

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- Designers of the New York Stock Exchange system wanted to guarantee continuous availability
- But they also wanted to use standards as much as possible
- Could they “overcome” TCP’s limitations?
  - Aside: didn’t want to work with the new real-time versions of TCP, which are poorly supported (and may not work all that well even under the best circumstances).

Goal of the NYSE application

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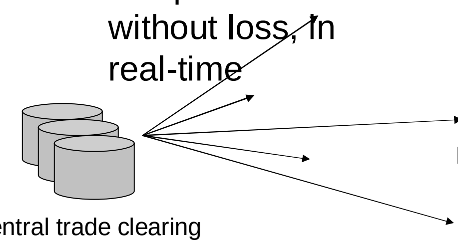
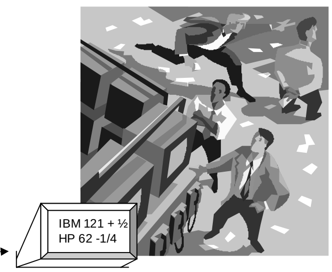
- Objective is to display selected data on overhead systems or other computers… without loss, in real-time





Built as a tree of application-specific routers

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- Router knows what the data demands of "downstream" nodes are
  - E.g. on the right, {IBM,HP,SUN…}
  - On the left, {GTE,C,MOBL}
- Incoming message?
  - Check contents
  - Forward copies on each "leg" interested in message of this type

The NYSE as a tree of specialized routers

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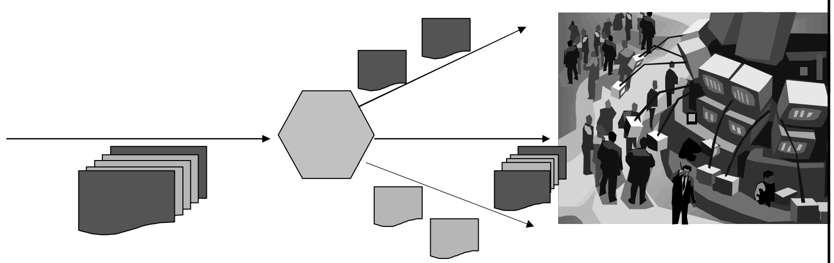

This is also called a "publish-subscribe" or a "content" routing mechanism….

Suppose we build this using standard technology?

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- TCP connection could
  - Congest, leaving system "stuck"
  - Break even if router is healthy
  - Exhibit unpredictable behavior
- NYSE needed to build on TCP but prevent these undesired problems!

NYSE approach

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- Begin by isolating the network
  - It has no outside traffic at all
  - Thus only load on a router is from the display subsystem itself
- This helps dampen the TCP congestion behavior

But transient failures and real failures are more of an issue

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- A *transient failure* occurs if a machine hangs briefly
  - Common on both Linux or other UNIX systems and on Windows
  - With Linux, seen when a device driver prints error messages
  - With Windows, issue occurs when an application locks a critical kernel resource
- Such problem can cause a system to hang for 30 seconds or longer – long enough for TCP connections to start to break!

What about real failures?

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- Issue here is that network can have many kinds of real failures
  - Routers can break
  - Cables can become lossy due to poor connections, noise, ground faults (usually due to moisture), etc
- Such problems may
  - Degrade a network but leave it limping
  - Cause bursts of failures
  - Cause real crashes
- They can be *very hard* to detect

Recall our goals

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- We wanted continuous availability
  - Now we're faced with *many forms of single-point dependencies* and *many ways that a single failure could cripple the system!*
- What alternatives could be considered?

What about building directly on UDP?

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- UDP would experience the same packet loss issues
  - RED also applies to UDP
  - And “real” failures impact UDP just as much as they impact TCP

NYSE opted for a third approach

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- They decided to build a “dual network”
  - Duplicate the entire tree
  - Physically separate and duplicated hardware and power supply
- They assumed that transient problems or physical problems would be unlikely to disrupt both at once

A new issue!

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- Now they confronted difficulty of controlling network routing
  - Internet routing protocols could decide to route packets entirely on one network no matter what we “ask” them to do!
- Solved by giving each machine two IP addresses
  - One network handled one set of IP addresses (10.1.1.1, 10.1.1.2, etc) and the other the second set (10.2.1.1, 10.2.1.2…)

Replicating state remains a big challenge

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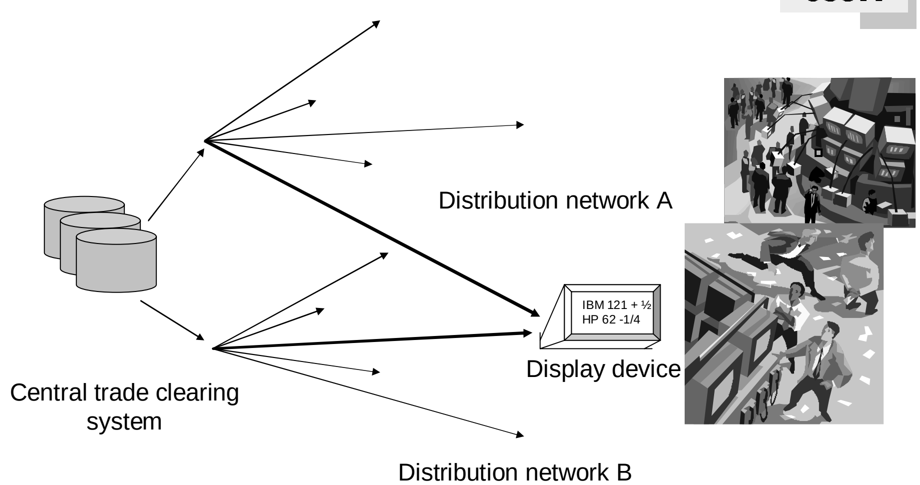

Replication requirement?

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- Two sets of routers with independent TCP links
  - But they need to behave in the identical way!
- This is another instance of the kind of replication issues seen before
  - Clusters need this kind of replication
  - So did our air traffic control system

Forms of state (of data) that need to be replicated

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- Set of data sources
  - If routers listen to different sets of sources, output will obvious be different
- Set of data receivers
  - If some router considers machine *x* to have failed and the other doesn't, *x* is at risk of single-point outages
- Data forwarding pattern
  - Routers should see identical inputs and forward data identically
- Even need to be consistent when changing the pattern!
  - Change forwarding pattern at some point in virtual time, not at an arbitrary moment
  - Use the sequence of messages as a time source

Replicating state remains a big challenge

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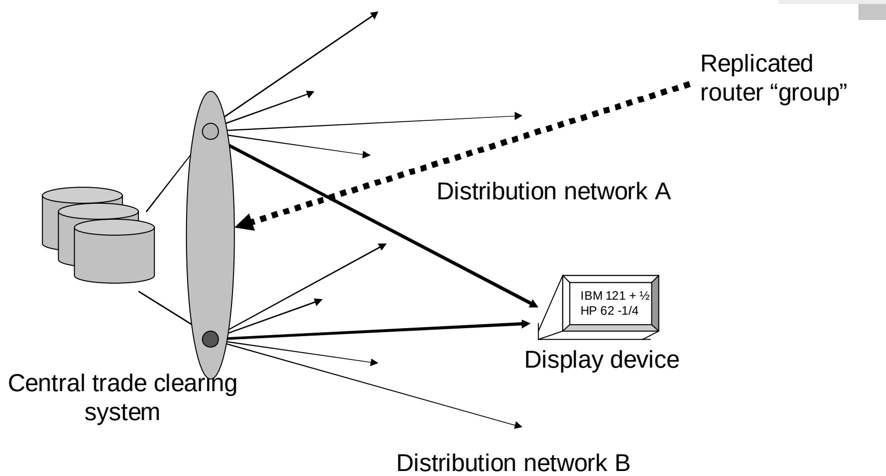

Replicated router tree

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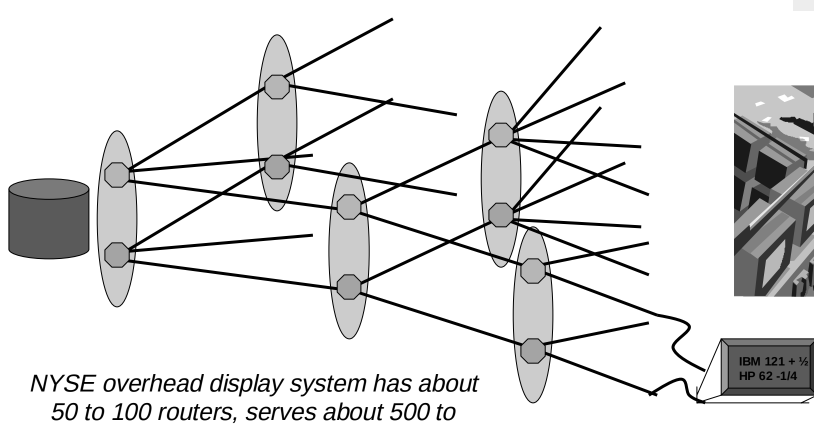

NYSE overhead display system has about 50 to 100 routers, serves about 500 to 1000 display units, plus SEC, Dow, Reuters, Bloomberg, etc

NYSE used a package called Isis for this

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- Ken wrote the system years ago
  - We'll discuss process group replication in more detail later, not important right now except as a useful mechanism
  - It includes a failure monitoring and reporting subsystem
- Isis itself needed to know about dual IP network
  - It was designed to use both networks concurrently as a way to ensure steady communication even during disruption

Additional real world issues?

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- Many corporate networks would love to get the levels of availability seen in NYSE or similar systems
  - But technology like Isis is non-standard
  - Moreover, real networks face *aggressive threats*, not just passive ones

Denial of Service Attacks

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- An increasingly common way to attack a network from the outside
  - A few recent events were insider attacks
- Goal of attacker is to flood routers or links and cause such high packet loss rates or loads that service is lost
- Often mounted from many attack sites
  - Hence *distributed* DOS or DDOS
  - Very hard to defend against

Challenge facing the most demanding, critical apps

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- Either build a totally isolated network
- … or live in a world of
  - Transient outages
  - RED and greedy TCP behavior. TCP slow start
  - Long delays to detect and repair problems when failures or sustained overloads occur
  - IP routing that won’t make use of network redundancy even if present
  - DDOS attacks and other forms of intrusion… insider threats too!